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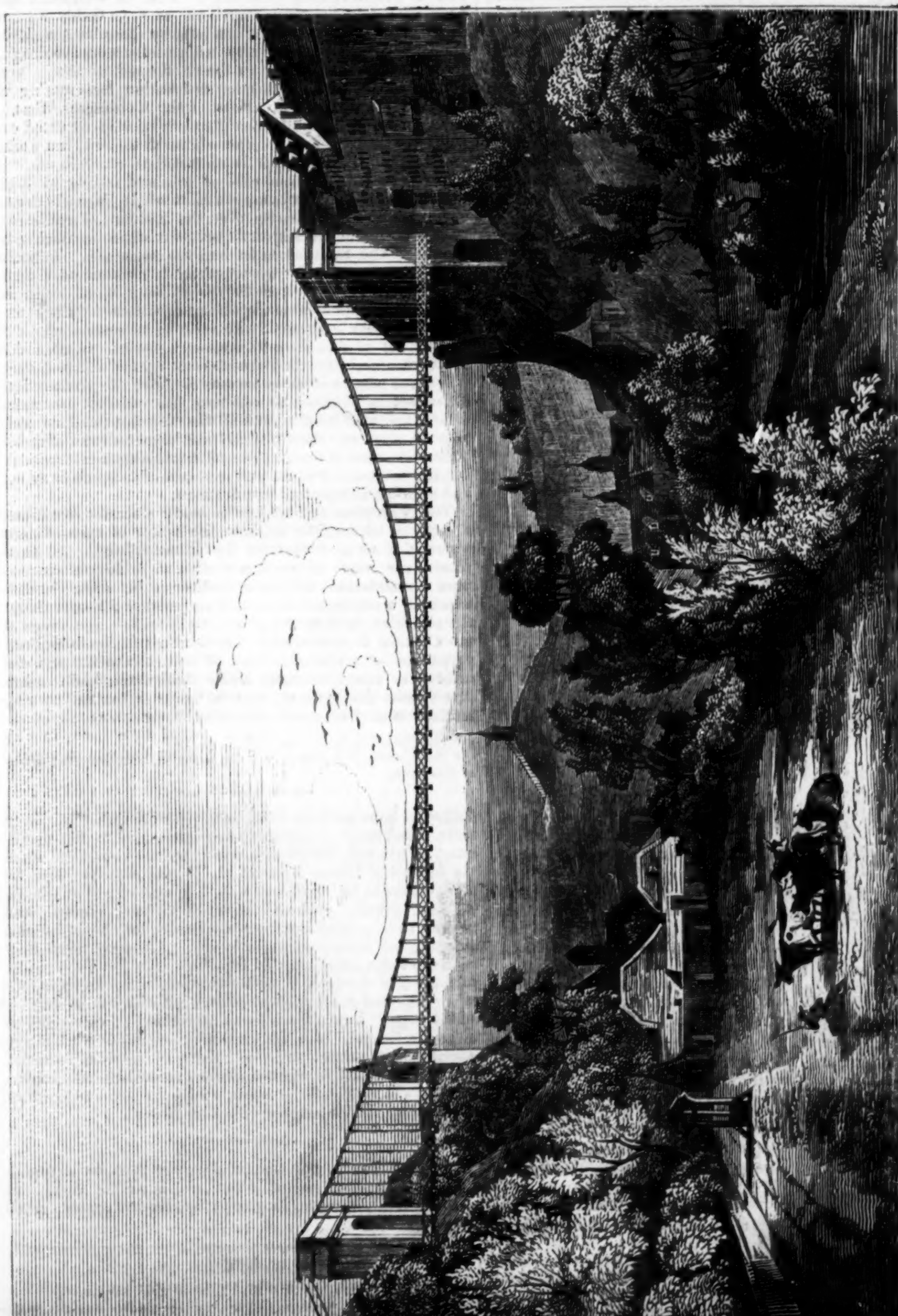


IRON WIRE SUSPENSION BRIDGE, FRIBOURG, IN SWITZERLAND.

SOME ACCOUNT OF SUSPENSION BRIDGES.

The extensive adoption of Suspension Bridges is far from the least important mechanical improvement which has distinguished the present eventful century; an account of the principles on which these bridges are constructed, cannot, therefore, but be interesting to our readers.

If a fallen tree, lying across a stream, served as a model for the earliest bridge, the slender stem of a creeping plant, swinging from bank to bank, may have suggested the possibility of suspending a rope-bridge across a river too wide to be spanned by timber beams in one length, when the rapidity of the current, or other circumstances, precluded the erection of intermediate piers.

So obvious, indeed, is the principle, and so easy the construction, of such hanging bridges, that they have apparently been adopted in every country where the people had materials, and possessed sufficient ingenuity to manufacture flexible ropes from vegetable fibres, or from hides. They were found to have been in use from time immemorial in South America, when that country was first visited by Europeans; and such a bridge, called a *Tarabita*, is to this day employed to cross the valleys and torrents of the Cordilleras.

A cable, made of strips of hide, or fibres of plants, is stretched across, from a post or tree on one side, to a wheel on the other; this wheel, or some other contrivance, being necessary to strain the rope tighter when it gets too slack. A basket, large enough for a man to sit in, is suspended by loops from the cable, and the traveller is pulled across by a smaller rope led to the shore. Frequently two such cables are set up, each sloping from one bank to the other, to facilitate the passage of the basket.

The bridge described by Baron Humboldt, as thrown over the river Chambo, in Quito, is of a better construction than the Tarabita. The main ropes, which are four inches in diameter, and made of fibres of the *Agave Americana**, are laid over rude timber frames on each bank, and secured behind them by being fastened to posts driven into the ground. The road-way is laid on these ropes, and consequently partakes of their curvature, thus materially increasing the difficulty of walking on it; but the traveller *can walk* over it, and there are side parapets to keep him from falling over. The bridge is named *Penipe*, and is 131 feet in span.

Captain Hall† describes a bridge over the Maypo, in Chili, the main ropes of which are six in number, three on each side the road-way: they are firmly secured to the rock on the highest bank of the river, and are carried over a timber frame on the other, which is lower, down to the ground, where they are fastened to trees, and to stout posts driven into the earth. Short vertical cords are suspended from the main ropes, to carry the horizontal ones, on which the transverse planking of the road-way is laid. The span is 123 feet; and the ropes being of hide, their elasticity causes such an undulation, that travellers usually dismount and drive their mules over before them.

The following adventure, which occurred at this bridge on the occasion of the passage of a body of troops, is narrated in the Memoirs of General Miller. The infantry passed without the smallest difficulty, as did also the cavalry, each man leading his horse, and going a few at a time. When the artillery came up, doubts were entertained as to the possibility of getting it over. Captain Miller, at length, volunteered to conduct the first gun: the *limber* was taken off, and drag-ropes attached to the carriage, by which the piece was to be restrained from descending the curved road-way too rapidly, while the trail was held up by two gunners; but, notwithstanding these precautions, the bridge swung so much from side to side, that the men lost their balance, and the gun was overturned; the carriage, by becoming entangled in the side parapet of thongs, saved it from falling into the river, but caused the road-way to tilt over so much, that every one on it was obliged to cling to whatever he could catch hold of, to save himself from dropping off into the foaming torrent sixty feet beneath. None dared, for some time, to venture to the relief of the party, expecting the bridge would break down every instant, especially if loaded with any additional weight: when, however, it was seen that nothing material gave way, two or three men crept along it to render assistance. The gun was with difficulty dismounted; the carriage taken to pieces, and so conveyed to the banks. Every one was saved, but the artillery was obliged to be sent four or five leagues round, to a ford lower down the river.

So well adapted is this form of bridge for crossing the mountain torrents and defiles of the Cordilleras, that, in recent times, one of great length has been constructed over the Santa, after a fruitless endeavour to build an arched bridge, at an expense of £40,000.

In all the mountainous districts of India and Central Asia, suspension-bridges, of ropes, or chains, have been in existence from the earliest ages. Mr. Frazer, during his tour through the snowy range of the Himmala mountains, saw, and has described, several. Many consisted, like the Tarabita, of a single rope stretched over posts on the banks; a kind of wooden saddle is made to slide on the ropes, over which loops are hung for the passenger to seat himself in, and he is hauled across by a line attached to the saddle. Such a bridge is called, in that country, a *J'hoola*.

Mr. Frazer was one of a large party which crossed the Touse by a rope-bridge of this kind. All got over safely, with the exception of a Ghoorka sepoy, who, having his wife among the troop, wished to take her across with him, lest she should be frightened in making the formidable passage alone. When they had got about half way over, the tow-rope broke: the man, anxious to rescue his wife as quickly as possible from her awkward situation, let himself down, intending to fall into the water and swim across with the portion of rope that remained attached to the saddle, pulling the woman after him. He unfortunately got entangled either in the cord, or in his dress, and was carried away by the current, and perished; thus falling a sacrifice to his conjugal affection.

Captain Turner, who was sent on a mission into Bootan and Thibet in 1783, crossed a defile in the mountains, near the river Tchin-tchieu, by a formidable bridge of this kind. It consisted of two ropes, made of the twisted stems of creeping plants, stretched across the chasm, parallel to and near each other; they were encircled by a hoop, in which the traveller sat himself, and holding one of the ropes in each hand, worked himself across. Nothing but the alternative of having to pursue a circuitous road of many miles, could induce a person unaccustomed to such bridges to cross by such means.

Near to this was another of a superior construction, over the above-named river itself, and called *Chuka-chazum* from its proximity to the castle or fort of *Chuka*. The river runs between precipitous rugged banks, of unequal height and declivity, in the steepest of which is a solid pyramidal pier of masonry, having an opening through the top for the road-way; in this opening, a strong double frame, like a door-way, is fixed. On the other side of the river, at a little distance from the bank, there is, on the corresponding pier, a square building, containing a chamber which serves as a sort of ante-room to the bridge. From the front of this building a covered gallery of timber projects to the edge of the river, a distance of about thirty-five feet.

There are five main chains of iron, to form the floor of the bridge, secured to the front wall of the building, and, after passing over the lower beams of the gallery, they are attached to the bottom of the frame in the opposite pier: another chain on each side of the bridge is fixed, nine feet above the former, to the top beam of this frame; and, being carried through the wall of the chamber, pass down to the ground, where they are secured, but in what manner does not appear. From these two upper chains hang vertical suspending rods to the outer ones of the floor chains, which they thus assist to support, while they form a parapet to the bridge; the roadway is covered with strips of bamboo. This structure is so ancient, that it has a fabulous origin assigned to it by the people of the country.

* This is the *American Aloe*, which is remarkable for the long period which elapses before it flowers. The fibres of this plant are very tough, and well adapted for making ropes of, for which purpose it is extensively employed in America. The French term thread of these fibres, *fil de pite*.

It may be mentioned here, that *hemp* is never the material of which the ropes are made, employed in the bridges of America or Asia, described in the text. The other vegetable products used for the purpose are *coir*, or the fibres of the cocoa-nut, the stems of the bamboo and other reeds, &c.

† Extracts from a Journal written on the coast of Chili, &c., in 1820, 21, and 22.

At about a day's journey from Chuka, the same traveller saw another suspension-bridge over the river, which approached in its principle of construction those erected in Europe at the present day. Two chains, four feet apart, were stretched across, carried over a pile of stones raised on each bank, and after descending through a sloping passage cut in the rock, they were fastened to a large stone at the bottom, which was kept down in its place by a mass of rock and stones heaped on it. A single plank, for a footway, was suspended four feet below the chains, by means of roots and creeping stems attached to them on either side. The bridge was seventy feet long, and was called *Selo-chazum.*

It is a remarkable fact, that now, when the advantages of suspension-bridges have caused their general adoption in the present century, (as we shall presently mention,) the English in India, when they have occasion to erect such a bridge in any part of their extensive possessions, adopt ropes of coir, split bamboos, and all those materials which were employed for the purpose, perhaps, 2000 years ago.

The first of these modern Indian bridges was erected in Calcutta, by C. Shakspeare, Esq.; the span being 125 feet, and the width 6½; the platform being made of bamboos laid on coir-ropes, suspended from others, as in those above described. And many others of similar construction have been since established.

It does not appear that this fragile and perishable kind of bridge was extensively introduced into Europe, for several reasons*; the chief of which, perhaps, was the early discovery of the arch, which admitted of the erection of more substantial structures; and it was not till the latter end of the last century, that the advantages of suspension-bridges attracted the attention of scientific men in that quarter of the globe, from the following considerations.

During the existence of the Roman empire, and the ages which succeeded its overthrow, commercial intercourse between the various states of Europe met with but little encouragement; hence, the construction of permanent bridges was only undertaken from absolute necessity, in the largest cities, and on the principal roads; while the impediment they caused to the navigation of the rivers was entirely disregarded, as being but little felt.

But when the rapid extension of trade, especially in our own country, required not only the erection everywhere of new bridges, but that the convenience of inland navigation should be consulted, the adoption of arches of considerable span, besides lessening the expense of such structures, also satisfied the last-mentioned claims. At length, engineers, having nearly attained the limits of construction of arches, turned their attention to suspension-bridges, both as considerably cheaper than those of stone, and admitting of application where the latter were impracticable.

It appears, from the accounts above given of Peruvian and Indian bridges, that, even with such light structures, more than one rope on each side was considered essential to security; not only that, if one gave way, the others might sustain the road for a time, till the injury could be repaired, but because several small ropes are proportionably stronger than one large one.

The same precautions were still more necessary with such suspension-bridges as were now contemplated, in which iron must be adopted as the sole material. The enormous weight of iron chains, independently of that of the road-way they uphold, not only requires an increase in their number, but that every precaution should be taken to render them equally strong in every part.

This latter condition is best fulfilled by making each link consist of several parts united together, because it is much easier to make a small bar sound than a large one, and if one such bar in the link should break, it can be replaced; and also because small rods can be *forged*, or *drawn*, and will therefore possess the superior tenacity of *wrought* iron over *cast.*

It is this last-mentioned quality that induces the employment of iron *wire* to form the chains of; each link consisting of numerous coils of such wire bound together†.

It has been found, by calculation and experiment, that there is a certain degree of curvature in a flexible chain or rope, when employed in a suspension-bridge, which is most conducive to stability‡; and since the lowest point of that curve, or the level of the road, must be elevated sufficiently above the river, or valley beneath; in order that the chains may assume that curvature, they must be suspended from a pier, or tower, of some kind, erected at each end of the bridge.

But it is obvious that no such upright structure could be capable of resisting the tension of the chains, even of a small bridge, if they were simply fastened to its summit. It is necessary, therefore, after carrying the chains over these piers, to bring them down again to the ground, and to fasten them either to some natural rock, or to an artificial mass of masonry, which, by its size and weight, may prevent the chains from subsiding in the middle of the span.

In order to avoid any lateral pressure that would tend to overthrow the piers, either way, it is requisite that the *weight* of the suspended mass should press perpendicularly on them. This is effected by causing the chains to descend from the piers, each way, at an equal angle: but this precaution is commonly sacrificed to other considerations, and the stability of the piers secured by additional size or strength, and by their pyramidal form.

And since every variation in temperature must occasion a change in the length of such a mass of iron, which will cause some *play* of the chains on the summits of the piers, an effect which would be also produced, though in a slighter degree, by any temporary vibration, the chains, instead of resting directly on the piers, are laid on *friction rollers*, which allow of that motion without its shaking or deranging the structures.

SUSPENSION-BRIDGES IN MODERN TIMES.

A CHAIN bridge was erected across the Tees, near Middleton, in Yorkshire, about the year 1741. This is said to have been but a rude work, little superior to the bridges we have above described. It was not till the year 1796, that any suspension-bridge of consequence was erected in modern times. This was accomplished by Mr. Finlay, over Jacob's Creek, near Greenburgh, in North America, and many others, either under his immediate direction, or according to his plan, were speedily constructed in various parts of the United States.

One of these, over the Merrimack, near Newbury Port, is a work of considerable size and strength: it is 244 feet long in one span; there are ten chains, three on each side, and four in the middle, forming two road-ways, each 15 feet broad; the chains pass over suspension pillars, 35 feet high, down to the ground, into deep wells, in which they are secured to heavy stones. This bridge is used for carriages, and cost about £5500.

In 1814, a plan was proposed for making a direct road from Runcorn over the Mersey to Liverpool, to include a bridge across Runcorn Gap, in lieu of the present ferry there. As it was necessary, on account of the navigation, that any such bridge should consist of three arches, or spans only, the centre one of which must be 1000 feet broad, and at least 70 feet high, a bridge of arches was out of the question, and the late Mr Telford proposed a suspension one. This was the first occasion on which English engineers directed their attention to the subject; and several small suspension-bridges, chiefly of iron wire, were, in consequence, erected in Britain, before the year 1820.

The first of these was thrown across the Gala-Water at Galashiels, in 1816: it was made of slender wire, with a span of 111 feet, and cost about 40*l.*§

* There are, however, several ancient bridges on this principle in various parts of Europe, as, for example, over the Arratis, at Stoffingen, in Switzertand, and several between Trente and Inspruch; the chains of which are long pieces of wood, put together with iron pins. There are also two or three in Franconia and other parts of Germany, all situated in mountainous countries, where recourse would be had to this kind of structure, for the reasons stated in the text. But, as all these bear but a small proportion to the bridges of the ordinary form in the same countries, we are borne out in stating them not to have been formerly ever common in Europe.

Suspension-bridges of rope have frequently been used in military operations, to facilitate the passage of troops and artillery; but these were only temporary structures, analogous to the pontoon bridges, &c., generally used in warfare. The French, in their retreat, having broken down an arch of the fine old Roman bridge at Alcantara, over the Tagus, a platform, carried on cables, was laid across the aperture, to enable our army to pass, in the early part of the campaign on the Peninsula. For a description and view of this bridge, see Sir Howard Douglas, *On Military Bridges.*

† The superior *tenacity* acquired by *drawing* is such, that iron *wire* will support at the rate of 38½ tons per square inch of its sectional area; while good *wrought* iron bars will only sustain 27 tons before they break.

‡ If this curvature were diminished by drawing the chains too tight, their own weight would rapidly increase the rate of *tension*, and thus weaken their power of supporting the road. Every one knows that it is impossible to stretch a cord or chain, of any length, quite straight in a horizontal line; long before it becomes so, it will break.

§ What would it have cost to erect a timber or brick arch, to answer the purpose? Certainly not less than thrice as much.

These bridges were not, however, on the present plan; but the road-way was supported by straight wires, proceeding from the top of upright posts at either end, to different points in the platform. This mode of construction was abandoned, in consequence of a bridge of 260 feet span, built at Dryburgh, on this principle, being totally destroyed by a gale of wind, six months after its erection.

It was this accident that pointed out to engineers the necessity for making suspension-bridges heavy and *stiff* enough to resist the tendency to increasing vibration produced by wind, or by carriages passing over.

In 1818, Commander Samuel Brown, R. N., the able engineer of many suspension-bridges and piers, took out a patent for making the links of the chains for such works, of straight rods, or bars, united by intermediate plates, with rivets or bolt-pins; and from that time, all the larger bridges in England have been built with these forms of chain.

The first was the UNION BRIDGE, erected in 1819 and 1820, across the Tweed, five miles above Berwick, by Captain Brown himself. The distance between the points of suspension, or the *chord-line*, is 449 feet.

The main-chains are twelve in number, placed in pairs in three ranges, one under the other, on each side; each link of the chains is a round rod, two inches in diameter, and fifteen feet long, formed with an *eye* at each end. These links are connected by means of short open ones, placed on each side of the longer, and united by bolts, kept in their places by a head at one end, and a pin, or *key*, which passes through the other. Each of the main-chains weighs about five tons, and the whole suspended weight is estimated at 100 tons.

This bridge, when it was first opened, was exposed to a severe trial, which must have been quite as great a one to the nerves of the engineer. The crowd of spectators broke through the toll-gates, and filled the bridge, to the number, as is stated, of 700 persons. So that, reckoning each at 150 lbs., the chains had a sudden additional weight of 47 tons to support; but they were not at all injured. Indeed, it has been calculated that this bridge would sustain a constant weight of 340 tons, in all, without danger.

The next important work of this kind, in which Captain Brown was engaged, was the TRINITY SUSPENSION-PIER at Newhaven, undertaken by the proprietors of the steam-vessels employed in the Frith of Forth, in consequence of the increase of intercourse with Scotland, by means of steam-boats; and after an unsuccessful negotiation with the Stone-Pier Company for the use of theirs, to facilitate the landing and embarking of passengers. The total length of this pier is 700 feet, which is divided into three equal spans, or separate bridges, of 209 feet each. At the land end, the tower to support the main-chains is of masonry; the three others consist of cast-iron frames, with a central archway for passengers. These frames are erected on piles, driven into the bed of the harbour, and the pier-head seaward is a platform 50 feet long, and 60 wide, supported by 46 stout piles. The main-chains, after descending from the last suspension frame, are securely bolted to cross-beams, fixed to these piles, and numerous diagonal braces and shores help to strengthen this work, to enable it to withstand the tension of the chains, and the rage of the open sea which breaks against it.

There are but two main-chains of the same construction as those of the Union Bridge; but there are, in addition, straight rods from the tops of the piers, to assist in supporting the road; and others beneath, fixed to the piles, to hold down the bridge, and counteract vibration. The whole, however, being intended for foot passengers only, is so slight, that there is a sensible motion even from the passage of a single person along it; yet it has weathered several severe storms without showing any signs of failure.

It is one of the advantages attending the employment of suspension-piers on the sea-coast, that, by the nature of such structures, they present but little surface on which the waves can act: accordingly, these piers are often overwhelmed by waves, without sustaining any injury.

AN ACCOUNT OF THE MENAI BRIDGE.

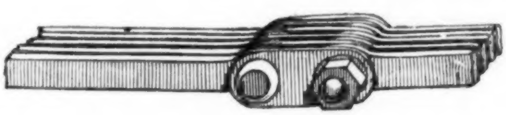
THE passage of the Menai Straits, between the Island of Anglesea, and the coast of Caernarvonshire, has always been a considerable drawback to the advantages of carrying the Irish mail to Holyhead, as the nearest point of embarkation for Dublin.

After repeated investigations, as to the best means of obviating this difficulty, and after protracted delays, caused by political events, Mr. Telford was directed to construct a suspension-bridge across the straits, which was began in July, 1819, and opened in January, 1826.

To appreciate justly this magnificent work, the reader should recollect that nothing approaching it in magnitude had, as yet, been accomplished. There existed, therefore, no precedent on which means for overcoming the various difficulties of execution, as they occurred, could be founded. Like his predecessors, Brindley, Arkwright, Watt, and Rennie; Telford had only his own genius to depend on; he, however, knew his own strength, and it did not fail him.

The view we have given of this bridge will supersede the necessity for any general description. The distance between the piers, at the level of the road, is 551 feet: the road-way is elevated 102 feet above high-water level, and is 28 feet wide, divided into two carriage-ways of 12 feet each, with a footway between them of four feet.

The main-chains are sixteen in number, the links of which consist of five wrought-iron bars, 10 feet long, 3½ inches broad, and one inch thick; consequently, there are in all 80 such bars, presenting a sectional surface of 260 square inches. The links are put together by means of coupling-links, 16 inches long, 8 broad, and one inch thick, in the manner represented in the figure, which is a view



of the bars constituting one chain at the junction of two contiguous links: each bolt-pin is three inches in diameter, and weighs 56 lbs.

The chains are arranged in sets of four, one under the other; one set on each side of the central foot-path, and one set on the outer sides of the bridge.

After passing over the piers, the chains descend to the earth, and are carried through three tunnels, cut in the solid rock on each shore, and are held in chambers at the ends of these tunnels, by means of twelve bolts, nine feet long, and six inches in diameter, resting in sockets in cast-iron plates six inches thick.

The portions of the chains that pass through the tunnels are made in every respect stouter than the rest, to allow for the greater degree of oxidation or *rusting* they are exposed to in such a situation, and where they cannot be easily got at to repaint them.

The *back-stays*, or the portions of the main-chains between the piers and the shores, though they have no road-way to support, are kept down by vertical suspending-rods, to prevent vibration; and the chains between the piers are stiffened against any *lateral* motion from the effects of wind, by means of eight cross-ties and bolts between them, and iron-netting again between each pair of these cross-ties.

The chains lie on cast-iron saddles on the top of the piers; these saddles resting on friction rollers, carried by an iron bed, which is fastened down on the masonry: the saddles, therefore, move with the chains, when these undergo any variation from temperature.

It is obvious that it would be impossible to make sixteen such chains, consisting of so many separate parts, so exactly equal in length, that when fixed in their places, they may all hang down between the piers equally: an adjustment is, therefore, required, by which those which are too long may be shortened a little when they are set up. This is effected by means of four adjusting links in each chain, one between each pier and the shore, and two between the piers. In these links, the *eyes*, or bolt-holes, at one end, instead of being circular, as they are at all the others, are lengthened into slits; they are put together with a corresponding slit in the coupling links, by two half-round bolts, which admit of wedges being driven in between them, which thus shorten the whole link, by diminishing the distance between this compound bolt, and the single one at the other end of the coupling link.

The chains were set up in the following manner: the parts within the tunnels in the rocks, were put together link by link, from the holding bolts at the bottom; a scaffolding was erected from the mouths of the tunnels on the masonry, supporting a platform of the proper inclination, reaching to the tops of the piers: the chains were put together on this platform, till they reached over the saddles.

A cradle, capable of holding two workmen, was supended

MENAI SUSPENSION-BRIDGE.

by tackle from the top of the pier, on the Caernarvon side, so that the men could raise or lower it themselves as they required. The links were brought to the face of the pier next the sea, through the archway; from thence, each link was raised to the proper height where it was wanted; it was then put on to the last by the men in the cradle: proceeding in this way, the chain was carried on downwards to the level of the water.

The remaining portion of the chain that was to unite the two ends, was laid on a raft 400 feet long, and six feet wide; one end of this piece being joined on to that which hung down from the pier, the raft was floated across, and the other end of the chain lying on it, was made fast by the *second* link to a powerful tackle, which was raised by two capstans on shore*, till the chain was elevated to the height necessary to admit of the two ends being united; the *last* link was left disengaged, to admit of the workmen managing the junction.

The first chain was thus raised into its place in an hour and a half, on the 26th of May, 1825; the remaining fifteen being got up in the same manner at different times. The road-way consists of two thicknesses of planks,—the lower three, and the upper, two inches thick; the under one is bolted to the wood that fills in the intervals between the road-way bars: this planking was covered with felt, saturated with boiled tar, and the upper thickness was laid over this felt, and spiked down to that beneath. In the middle of each carriage-way, there is a third thickness of plank, laid on felt, as before: the road-way is also stiffened by means of an oak-plank bolted to the underside, between each cross-bearer.

The bridge being completed, was opened on the 30th of January, 1826, six years and a half after its commencement. A few additions and corrections only were found requisite, which were immediately made, and since that time it has remained unimpaired†.

THE SUSPENSION-PIER AT BRIGHTON.

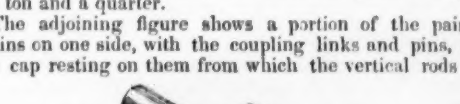
THE successful erection of the Newhaven Pier, proved that the suspension principle was equally adapted to such structures, as to bridges in ordinary situations. The great number of visiters annually attracted to the town of Brighton, by its favourable position, and its proximity to London, rendered the construction of a pier there a promising speculation, which was eagerly seized on; as the total absence of any natural harbour, or port, made all approach by sea inconvenient, and, in rough weather, impracticable; and, in a great measure, precluded the possibility of enjoying one of the chief sources of pleasure at a watering-place.

Accordingly, as early as 1822, Captain Brown was engaged to build a suspension-pier, which he commenced in October, and completed in the month of November of the following year. This beautiful structure runs out into the sea 1014 feet from the front of the esplanade wall; the entire length being 1136 feet, which is divided into four spans, or openings, of 255 feet each; the platform being thirteen feet broad.

The main-chains are eight in number, arranged in two pairs on each side the platform: the links are composed of round rods, not quite two inches in diameter, and ten feet long, with eyes at each end; and are put together with open coupling links, as those of the Union Bridge and Newhaven Pier. The chains are carried over pyramidal cast-iron frames, or towers, twenty-five feet high, resting on clusters of piles; of which the end one, at the head of the pier is spread out laterally, forming a T, and consists of 150 piles, strengthened by others driven in diagonally, and by horizontal bracings; and is covered with a granite paving, eighty feet long, by forty wide, and a foot thick, weighing upwards of 200 tons. The object of this strength and weight is to afford a firm base for the back stay-chains, which are bolted to the diagonal piles.

The main-chains are carried at the land end over a pier of masonry, and through two tunnels cut in the cliff thirty or forty feet deep; at the end of each tunnel is a brick chamber, at the bottom of which the chains are attached to massive stones, and finally to a cast-iron plate, weighing one ton and a quarter.

The adjoining figure shows a portion of the pair of chains on one side, with the coupling links and pins, and the cap resting on them from which the vertical rods are



suspended. The cap is cast with a square cavity within it, and with a slit, leading to the cavity; through this slit, the T head of the rod (shown apart at A,) being put, the rod is turned round, and the T then rests on the bottom of the cavity.

The two pair of chains are so contrived, that the pair of coupling links of the one set shall come between that of the other two chains: by this arrangement, the caps and

* One hundred and fifty men were required to work the two.

† The weight of the sixteen main-chains *between the piers*, including all their pins, plates, ties, &c., amounts to 398 tons; and that of the vertical suspending rods, road-way, planking, &c., is about 246 tons, making the *total suspended weight* 644 tons, which is equivalent to a *strain* or *tension* at each point of suspension, of 1100 tons. The sectional area of the sixteen chains will be found to be (80 × 3.25) 260 square inches, which, at twenty-seven tons per square inch, will bear 7020 tons *without breaking*: but to ensure permanence to a bridge, it should never be loaded at a greater rate than would produce a tension of nine tons to the square inch, that being found to be the ultimatum of weight that average wrought-iron will bear *without any stretching*. At this rate, the bridge would bear 2340 tons constantly, without injury, leaving a surplus of power of enduring over its own tension, of nearly 1240 tons, equivalent to 733 of direct weight. Now the area of the platform or road-way between the piers, is 15,240 square feet: allowing two square feet to each person, the bridge would hold 7620 persons, crowded as close as men can stand; taking 150 lbs. as their average weight, this number would weigh 466 tons, or nearly 300 tons less than the bridge could constantly bear without the slightest injury.

suspending rods, which are borne by every pair of coupling links, are equidistant, at about five feet apart.

The lower end of the vertical rod is formed into a fork, in which the longitudinal bars (B) are put, and kept up by a *key* and wedge, as shown in the figure; these bars serve to support the transverse joists of the platform.

This beautiful pier withstood several severe storms uninjured; but during the night of the 15th of October, 1833, a tremendous gale from the west, and therefore exerting its force at right angles to the length of the structure, caused sad havoc with it. The platform between the first and third piers was nearly entirely destroyed, all the suspension-rods broken, and the main-chains much deranged; while the weight of the road being removed at this part, caused the chains over the first and fourth spans to sink down, with the platform they supported; thus causing great additional damage.

This was another lesson to the engineers of suspension-bridges; teaching them, that it was not the simple weight of the structures themselves, and of the ordinary loads that might pass over them, that must alone be provided for; but the effects of vertical or lateral vibration, arising from large numbers of persons walking over in measured step*, or from violent winds, must also be guarded against.

The remedy consists in making the bridge heavy and *stiff* enough to resist any tendency to vibration; by means of transverse ties between the main-chains, as was done with those of the Menai Bridge; and in bracing down the road-way, by rods fixed at one end, to its under side, and at the other, to the piers.

Mr. Brunel executed two suspension-bridges, to be put up in the Isle de Bourbon, in situations where they would be exposed to hurricanes, and where, therefore, extraordinary precautions were requisite to prevent oscillation. The method adopted by that able engineer, was to fix chains *under* the road-way, in each span, to the abutments and piers; to these chains rods were attached, which were also fastened to the under side of the roadway, and therefore kept it from rising *upwards*, as the main-chains prevented it from sinking *downwards*. To counteract *lateral* motion also, the outermost underneath chains spread out wider than the road, so that the rods, or ties attached to them, prevent the road from moving sideways, as well as restrain it from rising.

SUSPENSION-BRIDGE AT HAMMERSMITH, DESIGNED AND ERECTED BY WILLIAM T. CLARK, ESQ.

THE metropolis may boast of possessing one of the most elegant, if not one of the largest, of these structures ever erected; and the Thames, by this addition, unites within a distance of nine or ten miles, magnificent specimens of every kind of bridge†. The Hammersmith Bridge, too, exhibits an example of construction not common in suspension-bridges; part of the road-way being *supported on*, and not hanging from, the main-chains.

There being no natural rock on either bank of the river, to which the main-chains could be secured, as is the case with most of those bridges we have mentioned, abutments of masonry were required, which, by their weight and magnitude, might be equally effectual. These are built of brick, faced with stone, and measure forty-five feet from back to front, forty wide, and fourteen deep, their top being on a level with the road-way: the weight of each of these masses is about 2160 tons, to resist the pull of the chains. These chains are carried through passages left in the brick-work; and, entering the *face* of the abutment, proceed to chambers where they are bolted by powerful bolts, at the back of massive cast-iron plates, bearing against the front face of the chambers.

The distance between the abutments is divided into three openings, by two suspension towers, or piers, forming Tuscan archways, supported by a rustic base, rising from the bed of the river; thus leaving three water-ways, two of 144, and the centre one of 400 feet.

There are eight main-chains, arranged in four lines of twos, in each of which the chains are over one another, and not side by side. The two *outer* lines of chains consist of links 8 feet 10 inches long, made of three bars, each five inches broad and one thick: the two inner lines of chains have each six such bars, or are twice the width of the others. There are, therefore, altogether, 36 lines of bars, presenting a sectional surface of 180 square inches: the links are put together with coupling-plates, fifteen inches long, eight broad, and one thick, in a similar manner to those of the Menai. The chains pass over friction rollers on the tops of the piers, as usual, but the rollers are supported in frames, so as to form two concentric arcs, one for each set of chains; the curves of the chains are tangents to these arcs, and the links that rest on the rollers are forged curved, to fit the arc formed by the set of rollers they rest on. By this construction there is no unequal strain on any part of the chains, and their pressure is made to act perpendicularly on the piers; the back-stays descending towards the abutments at an angle equal to that at which the chains between the piers descend from the rollers.

The platform is divided by the suspension-rods into a central carriage-way, twenty feet wide, and a five feet foot-path on each side. The transverse beams, supported by the vertical rods, are in pairs, resting on a square plate attached to the end of each rod: besides longitudinal beams bolted down to these, and all the other usual precautions for durability, strength, and stiffness, the longitudinal beams, on each side the carriage-way, carry a set of trusses, like those of the roof of a house, which contribute materially to this object.

The consequence of this admirable construction is, that the degree of curvature in which the road-way was originally laid, has not diminished at all, showing that no part of the abutments, piers, chains, suspension-rods, or framing, has given way; and yet the motion caused by a single carriage passing is perceptible to a foot-passenger, and the longer suspension-rods vibrate sensibly to the eye, proving that the strength and firmness is obtained by scientific skill in design and execution, not by a lavish expenditure of material.

The back-stays intersect the road-way between the abutments and piers, at about one-fourth the distance from the former to the latter; for this fourth, consequently, the platform is above the chains, the transverse beams being supported by iron plates, resting on the coupling links of the lowermost line of chains beneath.

This bridge was commenced in 1824, and opened in 1827‡.

As each link of an iron chain must be inflexible in itself, it would be exposed to an unequal strain, if it rested on one point only, instead of resting on its whole length; and this must happen if the chain, in any part, make an *angular* bend at any of its points of attachment. When experiment had proved the advantage of Captain Brown's construction, of chains with links from ten to fifteen feet in length, it became, of course, still more necessary to guard against the possibility of any one of these resting on one portion of its length only.

The means for obviating this source of weakness in the main-chains, consisted in shortening the links at that part of them that was bent over the suspension-piers, so that they might comform more nearly to the curved bed of friction rollers on which they lay; but chiefly in avoiding, as far as possible, all unnecessary changes in the direction of the chains.

The same remarks would apply to a wire cable, or to a rope even, though in a less degree: hence the English engineers carry the back-stays from the suspension-piers of their bridges, in one continued line, to the points at which they are fixed; though they are, in consequence, compelled to make them of considerable length, in order to get deep enough, in this slanting direction, below the surface, to

* Any body, susceptible of that motion, however heavy or massive, may be set oscillating or vibrating by a very slight force, if it be repeated at intervals equal, or *commensurable*, with those which the oscillations of the body would occupy; and the regular repetition would produce so much motion, that at length, the body, if fixed at two points, must break. Such is the kind of motion that would be produced in the main-chains of a bridge, by either of the causes mentioned in the text. A suspension-bridge at Broughton, near Manchester, was broken down by a party of sixty soldiers *marching* over it to a tune on a fife, on the 12th of April, 1831: the bridge would have borne more than double the weight, if the men had walked over it in *irregular* step. The accidents to the Dryburgh Bridge, and to the Brighton Pier, show the effects of wind, probably acting in gusts at equal intervals of time.

† We ought, in fairness, to except the wooden bridges at Battersea and Putney, which have nothing to recommend them but their being samples of *wooden* bridges. If the Tunnel at Rotherhithe is ever completed, our river will be unique. Those of our London readers who have not seen the bridge at Hammersmith, cannot do better than take a walk there directly; for it is not more than three miles from Hyde Park Corner. They will be amply remunerated for their trouble, if they consider the undertaking to be one.

‡ The reader will find a beautiful view of it in the late Mr. G. Cooke's work, *Views in and about the Metropolis*,

obtain a sufficiently strong hold of the rocky or artificial abutment.

In France, the engineers, to avoid this source of expense, enhanced as it is by the greater length of the tunnels to be cut in the rock, carry the back-stays down perpendicularly into the earth, after they reach its surface, and guard against the unequal tension on the links by forging them in a curved form, to fit the bed on which they lie at the turn, or else, when wire cables are employed, by spreading out the coils of wire composing them in several smaller bundles at the parts where they change their direction.

With these precautions, however, this mode of construction is objectionable, since the *pull* of the chains is not *perpendicularly* in the direction of this last portion, but *obliquely*, in that of the slanting back-stays; and, consequently, the vertical pit, or tunnel of masonry, is liable to be pulled over on one side, or at least deranged, though it might resist double the force, if it were only exerted in the same direction as its own axis.

The first suspension-bridge erected over the Seine, at Paris, by M. Navier, in 1823-1826, failed from this cause, and was obliged to be removed. It was replaced in 1829, by the present Pont des Invalides, constructed, in most respects, like ours at Hammersmith, which, apparently, was taken as a model for it.

The Pont D'Arcole is another suspension-bridge in that capital, which is made in two spans, by a central tower: but our space will not allow of our entering into any further account, either of these, or of many others on the Continent, preferring to devote all that we have, to a description of the longest suspension-bridge ever yet erected, and which is as yet little known in this country.

THE SUSPENSION-BRIDGE AT FRIBOURG, IN SWITZERLAND.

The city of Fribourg is situated on the brow of the rocky side of a deep valley, through which runs the river Sarine: in the narrowest part, the valley is only three hundred yards wide. The communication between Fribourg and Berne, and the rest of German-Switzerland was by a long, steep, and winding road down the valley, totally impassable in Winter, and dangerous at all times.

In 1830, the inhabitants having collected the necessary funds, and decided on the erection of a suspension-bridge across the valley, they confided the execution of their plan to M. Chaley, a French engineer, who has amply justified their choice, by the able and scientific manner in which he has accomplished his task.

The spot chosen was at the narrowest part of the valley, close to the town; the opposite side of the valley being about eighty yards higher than that on which the city stands, it was necessary to cut a road down through the brow of the hill, with a moderate declivity, to meet the level of that of the bridge.

The view of the structure at the head of this paper, will give the reader a general idea of the locality, the picturesque beauties of which are in no way impaired by the graceful form of this magnificent bridge. The suspension-piers are Roman-Doric archways, surmounted by a plain attic, the distance between the inner faces of which, or the distance between the points of suspension, is no less than 870 feet, or 301 more than that of the Menai. The road-way is 41 feet wide, and elevated 167 feet clear above the surface of the river: a semicircular terrace in front of the piers at each end, reduces the length of the *suspended* road-way to 807, which is 246 more than that of the Menai.

M. Chaley, contrary to our practice in Britain, decided on *wire cables* of suspension, of the form and construction of which we shall give a brief account, that the reader may judge of the comparative merits of this system, and that of iron *chains*.

The wire is ·12125 of an inch in diameter, and, by repeated experiments, was found capable of supporting at the rate of 52 tons 15 cwt. per square inch*.

* This result is so much greater than that at which English engineers arrive (see ante, p. 211) that we suspect some error in M. Chaley's work, from which our account is taken. Our readers may verify the calculations we made, the following being the data. The diameter of the wire 0·00308 metres. "And that, by repeated experiments, it was found to bear 82 kilogrammes per square millimetre." The French wire must be much better manufactured, and of better iron than ours, if there is no error. The whole of that used in the Fribourg Bridge, was made at Bienne, from iron of Undervilliers. It is worth recording, that M. Chaley thought it advisable to get the bolts and bars for his work from England, and states that, notwithstanding the great distance they had to be brought, they cost 20 per cent less than if he had obtained them from the iron works at Franche-Compté, within 30 leagues of Fribourg.

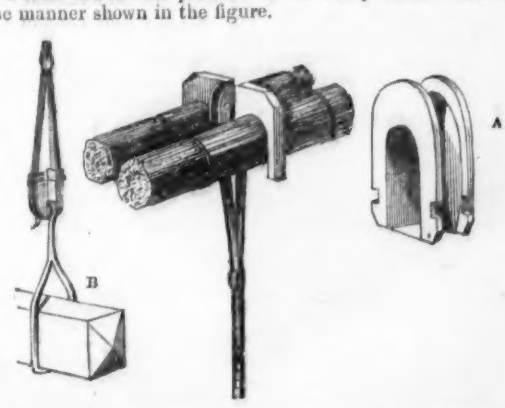
There are four cables; two on each side of the roadway, each consisting of 1056 wires, united into a cylindrical bundle, 5·314 inches in diameter, and bound round with thinner wire at intervals. Near to the piers, the two cables are separated into flat bundles, which rest on friction rollers on the summits, each roller being 31 inches long; and the bundles of wire extend over the whole of this space; after passing over these, the wires are again united into two cables, as before, down to the mouths of the slanting tunnels in the rocks. When they each divide into two, and continuing in the same direction to about the level of the ground, they are united to other cables, which pass down vertical wells, cut in the rock in the manner now to be described.

There are two of the slanting tunnels at each end of the bridge; one on each side to receive the four portions of the suspension-cables above-mentioned. At the end of each of these tunnels, there is a vertical well, or *chimney*, cut down in the rock to a depth of about sixteen yards.

The sides of the chimneys are cut out into chambers at three different depths; the backs of these recesses are hewed into the form adapted to serve as abutments to three masses of solid masonry, the courses of which form inverted arches, while the rest of the chimney between these arches is also filled up with masonry; the whole mass reaching to within about three yards of the tunnel, four vertical holes are left for the cables through the whole depth of this masonry.

These cables, which are four in number in each chimney, are each composed of 528 wires; the cables are 3·9 inches in diameter, and 27 yards long; at the bottom they are formed with loops or stirrups, through which strong bolts and wedges, or *anchors*, being passed, which lie across the bottom of the masonry, the cables are kept down immoveably, the inverted arched courses rendering it impossible for the strain to pull the masonry out of the chimneys.

On passing to the top of the vertical chimneys, the cables are carried over friction-rollers at the turn, and then along the slanting tunnels till they meet the ends of the suspension cables; both sets being terminated by stirrups or loops, they are united by half-round bolts, kept tight in the crossed loops by solid wedges. The cables are spread out into flat portions where they pass over the friction rollers, at the junction of the chimney and tunnel; this is done both here, and at the top of the piers, to avoid the unequal strain which a bend would produce in a thick cylinder, if the cables had preserved that form at these places. Like the cables, the suspending cords to carry the road-way are made of wire, thirty in each rod; there are 163 of these on each side of the bridge, the longest being 54½ feet, and the shortest only long enough to form a stirrup to receive the beams supporting the road; each cord terminates in a stirrup, made by carrying each coil of wire round cast-iron saddles, of the shape shown in the figure A. The upper saddle rides on a cross-plate; the two branches of this plate lie on the two parallel cables in the manner shown in the figure.



The lower saddle of the suspending-rods receives the hook of a square stirrup, into which the ends of the transverse beams carrying the roadway are put. (See the figure B.) Four ranges of beams are bolted down on these transverse ones, a space of twelve feet six inches being left in the middle between these longitudinal beams, for the carriage-way; the two beams being placed near each other on the outside of this carriage-road, to support planked foot-paths. The carriage-road was made by

spiking longitudinal battens, or small beams, immediately upon the transverse beams, and the planking was nailed on the battens.

It is obviously of essential importance to the strength of the cables, that every coil of wire composing them should be stretched equally tight, our readers will not be unwilling to be told how this object was accomplished.

Each cable was made in twenty separate *skeins* (if we may so term them,) of wire; 12 of 56 coils and 8 of 48 coils. Each skein of the whole length was made separately. The saddles round which the wire was to be turned, to form the loops, or stirrups, at each end of the skeins, were put round strong, upright pins, fixed into posts of oak, secured in the strongest manner from any lateral motion; the wire required to make each skein was put on a kind of reel or drum, which was carried on wheels; one end of the wire being temporarily attached to the beam near the saddle, the drum was rolled to the other end, suffering the wire to unwind off from it *. When the workman came to the other saddle, or end of the cable, the wire was put into a vice, attached to a cord passing over a pulley, and sustaining a weight of 200 lbs. and upwards; this precaution being taken at each end in succession, every length of the wire was stretched as nearly equally as possible. When the skein was completed and the ends joined, a ligature of of wire was put round each stirrup in the notch left for this purpose, and temporary coils were also wound round the skein at equal distances.

The skeins were all mounted into their places, and united to the end cables in the tunnels, before they were formed into the four cables they were to constitute. This union was done as the suspending rods were put up in succession; the temporary wire ligatures being gradually removed, and the twenty skeins pressed together into a cylinder by a wooden mould worked by a screw; when adjusted to the right form, the skeins composing each cable were bound round by coils of wire at equal distances.

* The wire, of course, was joined repeatedly for each skein; this union was effected before it was wound on to the drum. The ends of the two pieces, or hanks, were placed side by side for about four inches, and then wrapped round from end to end of the double wire with finer, each turn being close to the last, and drawn very tight. This mode of junction was found so effectual, that whenever a piece was proved, and broke in the trial, the rupture always occurred at the single wire, the joined ends never being pulled asunder in any instance.

Every part being completed, the bridge was publicly opened to foot-passengers on the 23rd of August, and on 8th of October for carriages of all descriptions. On the 15th, it was tried by causing a train of fifteen pieces of heavy artillery, drawn by fifty horses, and attended by 300 persons, to pass over the bridge at one time. Every part of the cables, &c. was subsequently examined, and not the slightest indication of yielding or weakness could be detected either in the iron, wood, or stone-work.

On the 19th, the bridge was publicly opened by the municipal authorities; on which occasion 2000 persons were at once on the road-way, and crossed it in measured march with military bands †.

M. Chaley concludes his account with an honest and generous exultation, that he had accomplished the whole of this construction not only without the loss of a single life, but without one of the workmen having met with any serious accident,—a fact reflecting the highest credit on all parties; on the engineer, as proving his attention to this point, and on the workmen, as proving their steadiness and sobriety.

The principal data for this paper are taken from the able work of Mr. C. S. Drewry, *A Memoir on Suspension-Bridges*, who allowed us to make this use of it. The account of the Fribourg Bridge, is abridged from the *Notice sur le Pont Suspendu le Fribourg*, by M. Chaley. The other works that have been referred to, are Provis's account of the Menai Bridge, Sir Howard Douglas on Military Bridges, and the various books of travels cited in our account.

† The total suspended weight of the bridge is nearly 296 tons, considerably less than half that of the Menai Bridge. The greatest load to which it can ever be subjected is about 158 tons, making together 454 tons; this, by calculation, gives a tension on the chains equivalent to 835 tons. M. Chaley, by estimating the ultimate strength of his wire at 1348 lbs., states his bridge to be capable of bearing three times the greatest load it can ever be exposed to; but, even taking the strength of the wire at 1000 lbs., which is nearer our English standard, the 4224 wires of the cables would bear 1885 tons. It must, however, be remembered, that the strength of a *cable* of wires cannot be estimated at that of the wires of which it is composed. However, by making every allowance, the Fribourg Bridge is perfectly safe, as far as mere *dead weight* is concerned. We should be sorry to forebode evil to such a work, but we cannot help apprehending a weak point in the apparently unnecessary angle in the main chains, caused by making the chimneys vertical, instead of continuing them in the direction of the tunnels and back-stays. We presume the necessity for cutting the drain so much longer was the objection to our plan.

A J'HOOLA, OR ROPE-BRIDGE, OVER A TORRENT IN THE HIMMALEH.

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